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TRANSMISSION OF CHARACTERISTIC DATA AND RANGE MEASUREMENT IN AIR-TRAFFIC CONTROL

T. Feger

ABSTRACT

Within the scope of general studies on the automation of air-traffic control, the Institute for Aviation Radio and Microwaves has developed a simple system for measuring the range between ground control stations and aircraft and a system of data transmission from the aircraft to ground stations. The operating principles of the systems have been tested and this report describes the technical details of the test arrangements for both the systems. It further includes systems analysis studies on the possibilities and the practicability of these accessory devices in present and future air-traffic control systems.

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1. Introduction

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On the basis of a research project assigned to the Institute in May 1957 for investigating the possibilities of preventing collisions in aviation (preliminary consideration), a government research grant was issued after a more detailed specification of the subject under the revised title of "Investigation of the Possibilities of Automating an Aircraft Landing-Control System".

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*Numbers given in margin indicate pagination in original foreign text.

This change was due to an interim report of the Institute of May 1959 which demonstrated that the task of preventing collisions in a cooperative flight-control system is an integral part of the larger task of automatic control systems.

The treatment of the control system in landing [illegible] is, from the viewpoint of scheduled air traffic, a priority task in short-range traffic. Its solution is dependent, upon more detailed consideration of the problematics, on the control system of both long-range and short-range traffic and subordinate in subject and time to the former. Consequently, the present investigation does not concern itself directly with landing but is restricted primarily to the movements in short-range traffic and to the landing approach. The Institute gratefully acknowledges the financial support of this research project by Land Nordrhein-Westfalen which made it possible to investigate not only the theoretical principles of the overall problem but also to carry out practical work for partial solutions of this task.

2. Principal Considerations in Development of the Components of an Automatic Flight-Control System

The automation of a flight-control system is, from the systems analysis viewpoint, dependent upon the means and on the form in which all data required for control and guidance of air traffic are received in the control center. In the intermediate phase of semi-automatic operation, a computer serves primarily for the processing of the data which are equivalent in regard to extent of accuracy to those on which the customary system is based (radio voice communication, primary radar equipment and telephone transmission). 18

The transition to full automation takes place not only by a progressive improvement of the efficiency and of the increased utilization of radar equipment but above all by the introduction of new data-transmission systems, in

place of voice communication, which must be adapted to the flight-control computer.

It is characteristic for these data that they originate in the aircraft and are not measurable from the ground and consequently require cooperation between ground and aircraft. Obtaining information at times determined from the ground conditions the selective character of the responses. The technical problems of such two-way communication here are manifold and cannot be outlined a priori because they mesh too closely with the other components of the closed control circuit of the flight-control system which are also variable in the development process. The consequence of this is that such systems can initially be developed only for experimental operation, and final improvement can result only from operational testing.

Another form of the cooperative control circuit "ground-aircraft-ground" exists in the secondary-surveillance radar system with a manner of operation predetermined by the radar system, specifically in regard to selectivity. For this reason, it was not clear at the start of the work described here whether the further development of flight control in view of automation of processes would have as primary basis the application of secondary-surveillance radar systems or the creation of a two-way data-transmission system, e.g. the AGACS-system (ref. 1).

This was the situation existing at the beginning of our practical work [19] which induced us to attempt partial solutions attractive by their simplicity and ease of expression, which in all likelihood will remain so, unless they themselves grow into more complicated techniques. The eventual development of international tendencies for modernizing flight control does not indicate any reason to change our viewpoint in regard to the actuality of the concept of our task.

Subsequently, system analysis of a future flight-control system became shifted, through the difference in the state of technology of the two possible systems mentioned, from the automatic data-transmission system to the secondary-surveillance radar (ref. 2). In the report on "Project Beacon" (ref. 3) prepared by a special committee for the "White House in Washington" in 1961, it was made clear that the data required for the future flight-control system can and should be derived under the present state of technology primarily from ground-based means. With the suggested distribution of primary and secondary radar equipment — and in the US, in connection with the existing and developing air defense system (SAGE) which is based on secondary radar — this information can be obtained which heretofore unduly occupied radio voice communication and could only be obtained from the ground, specifically the altitude of flight. We should like to quote verbatim from this report:

"It will have been noted that no automatic aircraft-ground communication equipment such as is now under development by FAA is required for the recommended system. Military development projects have shown that such equipment is possible and can be developed within the frame of the given technical prerequisites. However, within the near future there is no expectance of the development of instruments which are sufficiently inexpensive and light in order to be utilized generally. Further developmental work in this field therefore does not seem to be indicated at the present time. However, it is believed that an automatic aircraft-ground data-transmission system may represent some time in the future an important complement of the system, although this time is regarded as so far in the future that a continuation of the developmental work under the present state of technology does not seem

justifiable. Nevertheless, further technical work on this system should include an investigation of automatic data-transmission systems" (ref. 4). /10

If we examine the present attempts of modernizing flight-controlled systems, we will note that no change has taken place in the direction of an effective increase of the efficiency of the system in regard to the type of information. The initial efforts of individual countries therefore are intended to automate the routine and complicated manual partial systems with their still inadequate data. Although data transmission in the secondary radar system has been prescribed in ICAO-Specifications and the required ground instruments for experimental and testing operation have been installed at various locations, practical operation is now restricted to the identification of a few aircraft equipped with identification instruments (ref. 5). It was shown moreover that the secondary-radar data-transmission system is deficient (ref. 6), so that in the near future it will only complement information from primary-radar equipment in manual flight-control operations.

At the Symposium of the Ministry of Aviation Electronic Engineering Association in England, September 1963, experience with experimental secondary-radar operation indicated that secondary-radar systems require much improvement for the "cooperating loop" and are now inadequate for future operation (ref. 7). A two-way (ground-aircraft-ground) data-transmission system is required for future optimization. Such systems are now being developed digitally in England (ref. 8).

Both cooperative systems require high expenditure for equipment in the aircraft and on the ground. It is further anticipated that a general introduction and definitive scheduling within the flight-control system cannot be realized within the next 10 years. Some smaller planes will be excluded /11 from this

operation because of the high expenditure for equipment on board the planes. It will not be possible to close this gap exclusively with the help of radio-voice communication.

The enforced slighting of present-day flight-control systems due to the present orientation of long-range planning, therefore made it necessary to consider whether the presently existing serious inadequacies could not be eliminated by interim solutions, provided the latter can be incorporated into the organic structure of present-day flight control systems without modifying the latter. The introduction of such complementary installations becomes especially attractive if their continued use is possible to a certain extent even under progressive automation of flight control systems.

In order to acquire practical experience which could not be obtained in the near future from the long-range international concepts, we decided to undertake the solution of two minor partial problems experimentally, i.e., the development of range measurement as well as the automatic data transmission of identification and altitude of aircraft over radio voice frequencies. We started from the thought that the introduction of completely new (semi-) automatic transmission systems cannot take place for several years and that standard VHF radio-voice communication will remain the backbone of the flight control system. There existed and continues to exist the challenge whether minor additions to the aircraft equipment and the creation of suitable ground installations would lead to a simple solution of both range measurement as well as transmission of characteristic data.

The thought is here less to find a new national interim solution, even if such a solution would still be quite justified, but to initiate instead a development which would, even with the introduction of highly complicated data-

transmission systems, still constitute and continue to constitute for the future a logical solution also for non-scheduled and amateur flying. The following [12] reports on some partial results of the work carried out in recent years.

3. Range Measurement Over Radio-Voice Channel "Ground-Aircraft"

3.1 Statement of the Problem

The importance of range measurement for the respective aircraft position to the control center at the airport is shown by the fact that flight control, in recent years, has equipped its stations for the control of incoming flights with cathode-ray direction finders which, in the operation of radio-voice communication, flash an illuminated line on the screen of a Braun tube indicating aircraft bearing and serving as aid in identification. This indication may lead easily to erroneous conclusions if several planes come in simultaneously from the same air-traffic lane, i.e., appear from the direction-finder location under practically the same azimuth. However, if it is possible to obtain simultaneously with the bearing an indication of range of the aircraft or if the illuminated line can be limited in length as a function of range so that it corresponds to the actual geographic distance of the aircraft position, then it is easily possible to distinguish between the stacked aircraft.

Utilization of possible range-measurement locations from already existing radar-screen images is not possible and/or represents too high an electronic expenditure in order to obtain a numerically selective indication.

Consequently the thought arises of using the capacity of the radio-voice channel, which is only very incompletely utilized by radio-voice communication due to its low density of information, for the transmission of additional information (phase measurement) as well.

In addition to the transmission of charactistic data in the direction aircraft-ground which requires a certain expenditure for the coding instruments in the aircraft (cf. Sec. 4), the distance can be determined over the radio-voice channel through supplementary installations in simple manner from the principle of phase measurement of a low-frequency sinusoidal oscillation in travelling over the distance ground-aircraft-ground. The selection of the location for receiving the information on range or distance is decided by the real requirements of flight control and the necessity to base the main expenditure for instrumentation and equipment on the ground, in favor of measurement of range from the ground. In the interest of an optimum short-interval measurement procedure and accuracy, the latter should be optimally automated and should make no demands on the aircraft pilot.

3.2 Basic Principle of Range Measurement

The task consists in transmitting from the ground a sinusoidal low-frequency modulation selected for unique resolution of range, providing for reception in the aircraft, and for phase-stable re-transmission. After reception on the ground, the phase of the incoming oscillation is compared with the phase of the transmitted oscillation. The measured phase difference in the path of transmission ground-aircraft-ground is a direct measure for the (angular) distance between ground and aircraft.

With the physical elementary relation $\lambda = \frac{c}{f}$ and the proportional formula $2r : \lambda = \varphi : 360^{\circ}$, there results the relation for the phase difference $\varphi_{deg} = \frac{720 \cdot f \cdot r}{300{,}000}$, when r is the slant range in km, and f = frequency in cps.

With $\varphi = 360^{\circ}$, there results at a given frequency the maximum uniquely measurable distance and/or the required frequency of modulation for a desired range of distance.

EXAMPLE: At a distance of 100 km and a phase evaluation between 0° and 360°, this distance is uniquely resolved at a frequency of modulation of 1500 cps and, at a distance of measurement of 10 km, with 15 kcps. 114

3.3 Demands on the System on the Basis of the Measurement Principle

The entire phase-frequency characteristic is divided into

a) the phase ~~rotation~~ shift to which the signal is subjected in travelling through the electronic installations in the aircraft and on the ground, and

b) the desired ~~rotation through~~ phase shift depending on the travel time in the transmission medium, air.

Phase ~~rotation~~ shift as in a) is constant only in the ideal case and must be compensated by a single correction. The influence of variation in operating voltages (on-board power source) or transmission level may also cause instabilities of phase-frequency characteristics. Adequate phase stability can be provided as shown by earlier investigations (ref. 9) so that there are no difficulties from this direction.

Disregarding the possibility of interference by other voice modulation during the short interval of measurement or by other interferences, the desired information as in b) can be falsified by indirect radiation (analogous to the "ghosts" in television reception or to the course-bearing displacement in radio guidance from a localizer).

It should be kept in mind further that, when using phase detectors with a discrimination from 0° to 180°, the unique range of measurement is halved. Absolutely necessary is the accuracy and stability of the oscillator for the measurement frequency whereas the nonlinear distortion coefficient depends only conditionally on the type of phase measurement.

3.4 Measurement Method Selected and Investigated 15

For measurement of phase difference between two sinusoidal oscillations of the same frequency, a number of methods is in use. An example is a phase-measurement instrument which was developed during the present investigation for calibration and verification purposes (cf. circuit diagram in figure 1).

In this instrument, the two low-frequency signals differing in phase (f = 100 to 5000 cps, amplitude = 1 to 20 V) are conveyed to two identical channels in which both signals are transformed into analogous impulses by means

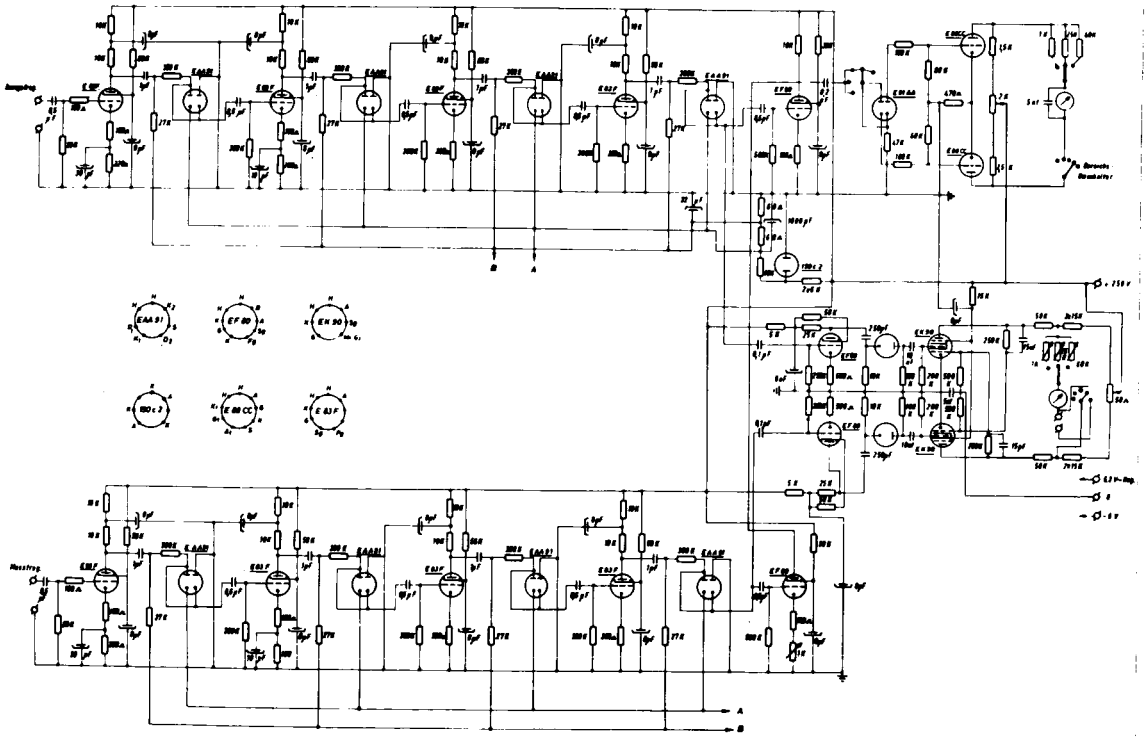

Figure 1. Circuit diagram of ~~electric~~ electronic phase meter.

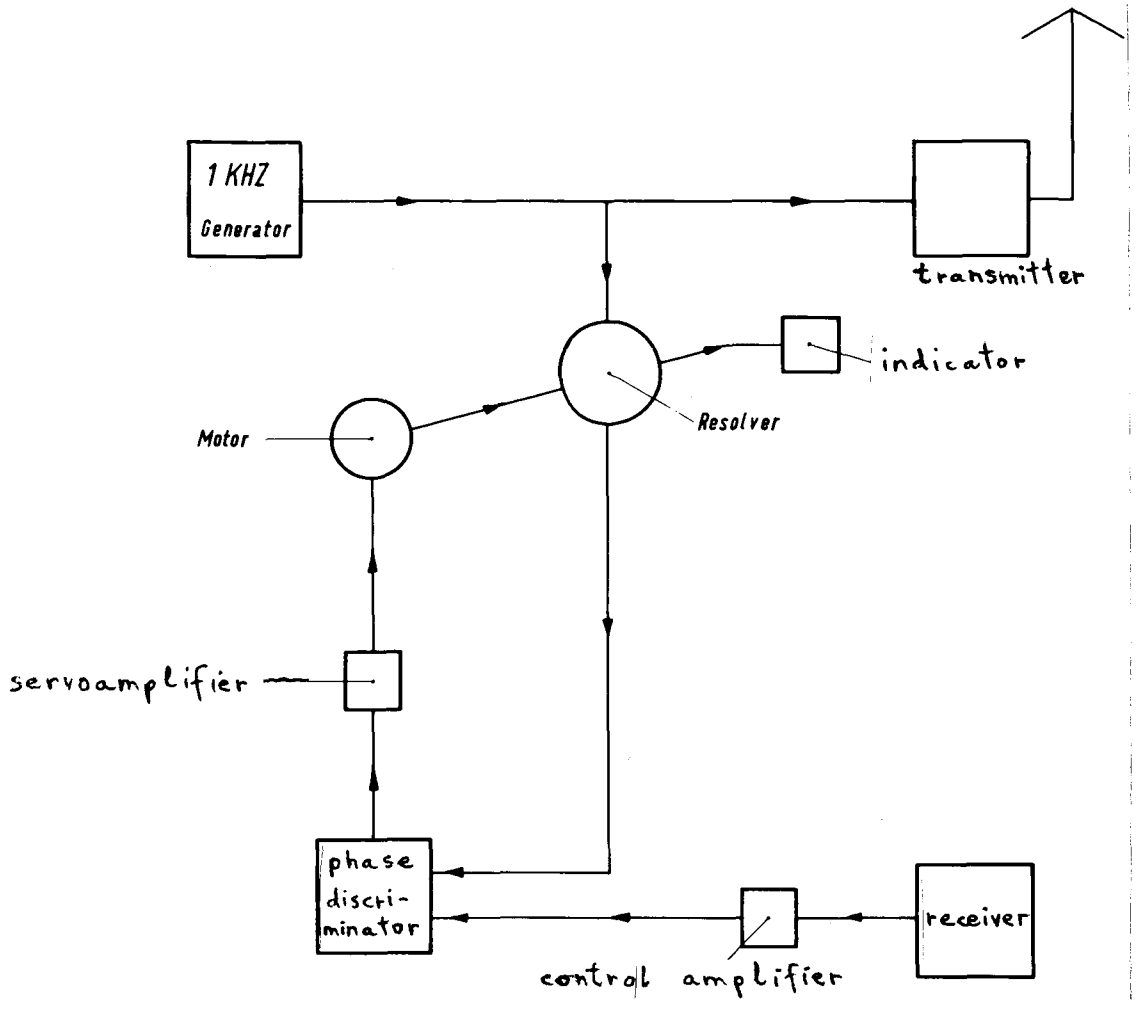

Figure 2. Circuit diagram of range measurement.

of amplifying and limiting stages. In the subsequent integrating circuit is generated an impulse of constant amplitude with a pulse width which is a measure of the signal phase shift. Parallel to the integrator circuit, both impulses are differentiated and conveyed to a discriminator circuit. The negative impulse peaks control a trigger circuit with two tubes where the anode current common to both is a measure for the interval of time between the two voltage peaks and consequently represents a measure of the phase difference between the signals.

By adding three shunt resistances to the instrument, three measuring ranges between 0° and 360° can be adjusted. During the measurement process itself, the integrated indication must be set for maximum. The reading is given by a milliam___meter which must be calibrated against known phase shifts.

Although the utilization of such measuring instruments for the present purpose can be considered, they have the disadvantage that they must be continually calibrated and furnish an analog potential at the output which is restricted to an indication on the instrument itself without storage of the indicated value.

Other simple measuring methods eliminate themselves due to the necessity for a time-consuming manual compensation. We should mention here the range-measuring instrument T-2002 developed by Siemens & Halske during the last war which represents the precursor of a measurement instrument for the present task (ref. 9). In this installation, it was necessary to convert by manual compensation the ellipsis recorded on a cathode-ray tube as representation of two phase-shifted signals into a straight line (criterion of zero phase). The compensating device was a phase shifter with an indication of phase shift corresponding to the distance. In this measuring method, the response from the aircraft takes place over another frequency.

In the present state of technology, the utilization of a "resolver" as accurate phase shifter for compensation to zero phase through time lag in the closed control circuit appeared particularly advantageous. It was investigated in the present study. This results in a circuit diagram of the phase meter shown in figure 2.

3.5 Experimental Design of Control Circuit Components From the Basic Circuit Diagram

a) Impulse generator

The measuring frequency for the experiment was 1 kcps. The impulse generator consists of a 1-kcps crystal oscillator provided with a separating and amplifying stage and furnishes the sender and resolver with appropriate transmission levels. Special attention was given to an optimum low distortion factor (circuit diagram shown in figure 3).

Since a longitudinal oscillator with such a low frequency requires a long build-up, it is necessary to keep the quartz oscillator in continuous operation

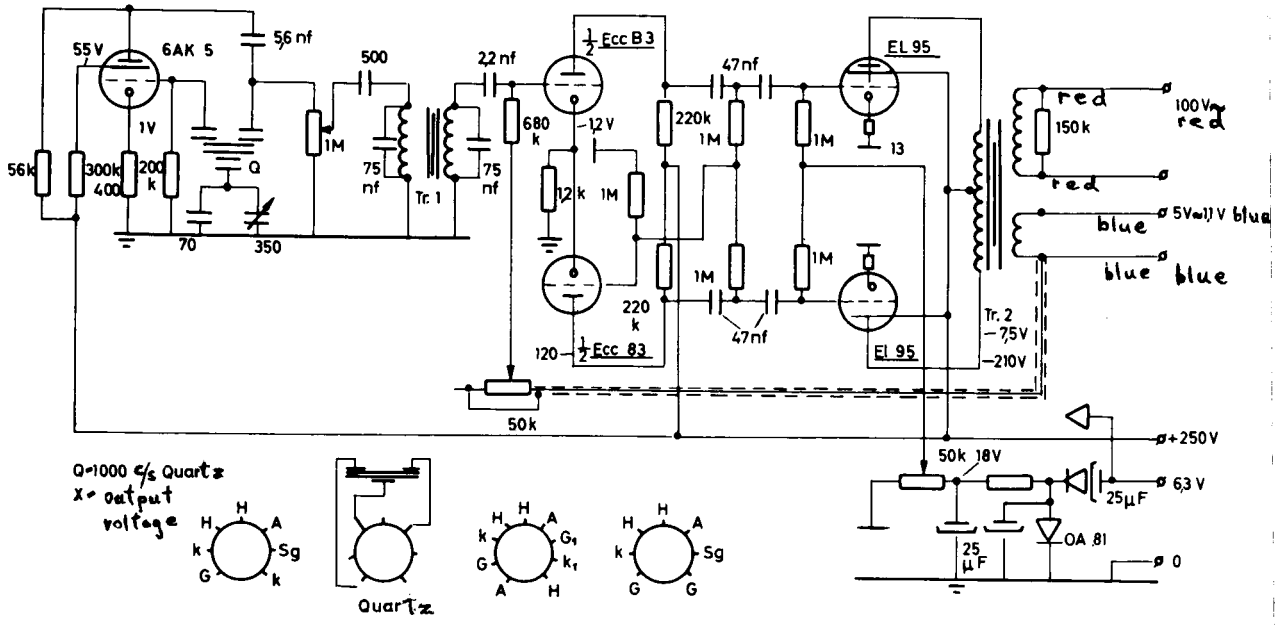

Figure 3. 1000-cps quartz generator for range measurement.

and to stabilize it (for temperature in the final design).

b) Phase Shifter

A resolver serves as accurate phase shifter (0° to 360°). We selected a commercially available model (Reeves TD #67) of optimum accuracy (ref. 10). The resolver serving for representation of a signal shifted from 0° to 360° at 1 kcps requires a circuit as shown in figure 4 and is matched ~~noninteracting~~ directly across a cathode follower to the phase discriminator.

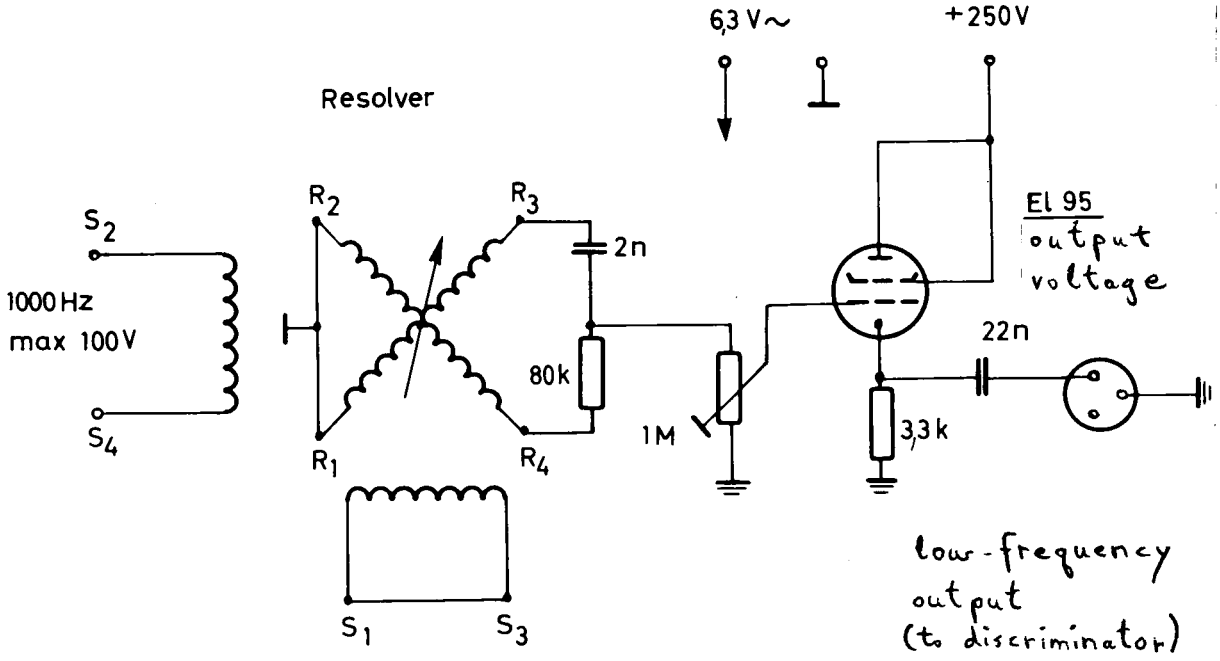

Figure 4. Phase shifter, with cathode stage, of range-measurement instruments.

c) Phase detector

The phase detector in this application serves to furnish an oriented potential as a function of phase which rotates the servomotor across the amplifier either left or right and stops the motor at zero phase (zero potential). The identification of the zero phase is consequently the deciding task of the phase detector. For this a simple phase detector is sufficient. It consists of a double triode with the cathode conduction in common producing in the "anode bridge" the required polarized potential if potentials of equal frequency and magnitude but different phase are supplied to the two grids (circuit diagram, cf. figure 5 bottom left).

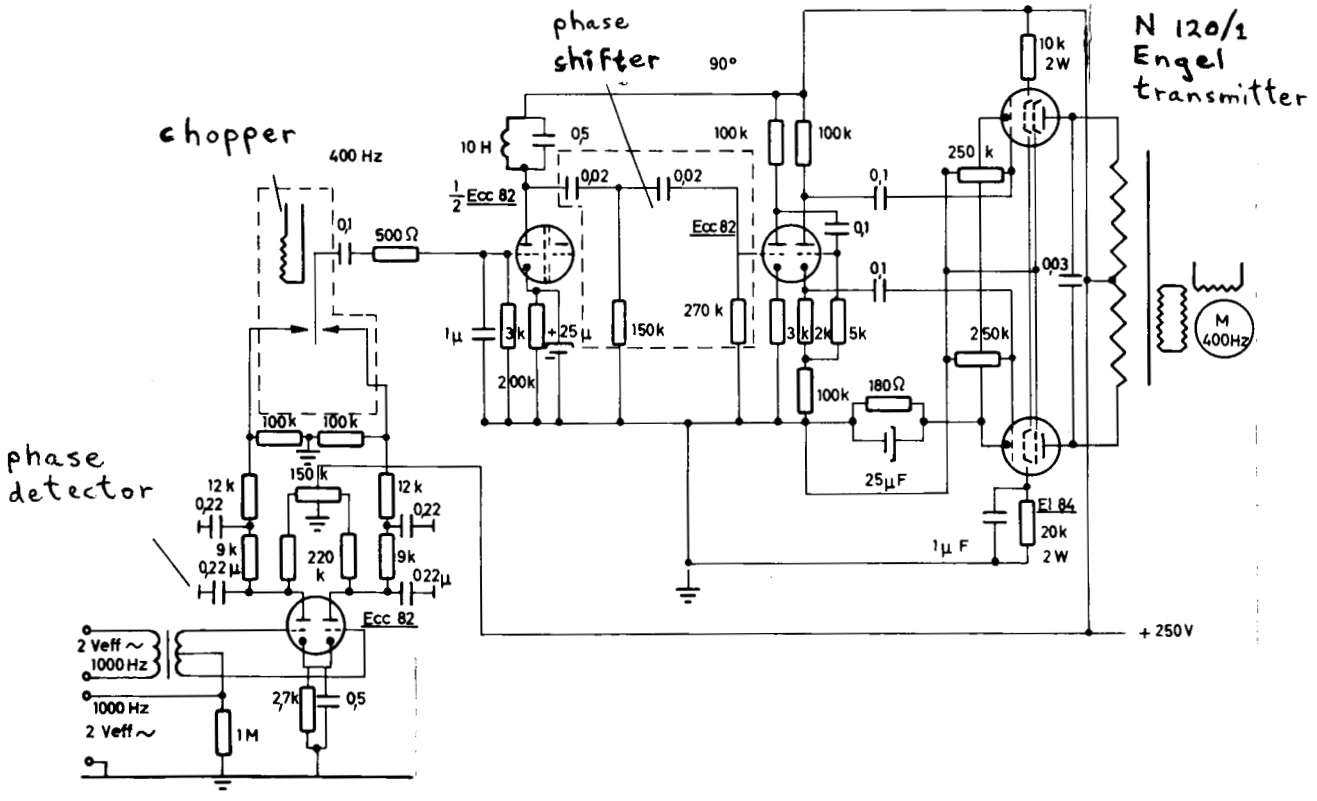

Figure 5. Ac servoamplifier or range-measurement instruments.

The output signal of the aircraft receiver already possessing controlled amplification must be brought, when utilizing this phase detector, to the transmission level of the non-delayed reference impulse by means of an additional control circuit. This makes necessary the incorporation of an additional three-stage control amplifier which keeps this transmission level strictly constant.

d) Servoamplifier

We initially utilized a servoamplifier with two thyratrons in phase opposition such as is frequently employed in industrial electronics (circuit diagram in figure 6). This operates with its firing point in horizontal direction (ac for anode) with a basic setting of two phase-shifted ac-voltages and is controlled in the vertical direction through changes of the polarized dc-voltage. It was shown, however, that traces of the ac components in the zero impulse cause instability in control around the zero point (favored by a common harmonic of the current-supply frequency with the measuring frequency). 118

We therefore replaced the thyratron amplifier by an ac-amplifier (with ac-servomotor). This necessitates transformation of the ac-error signal by a measurement chopper (circuit diagram in figure 5). A normal dc-amplifier was not considered because of the known difficulty of keeping the zero level constant. Experiments with different servosystems were shown to be necessary because the required accuracy of measurement can be increased only through matching of the control systems to the accurate resolver. The accuracy of the coarse system therefore requires stable control for zero because absolute standstill at zero must furnish the criterion for switching to fine-phase measurement and the fine system can resolve uniquely only within the respective sinusoidal characteristic. Otherwise there exists the risk that fine measurement will lead to deterioration of coarse measurement. The selection

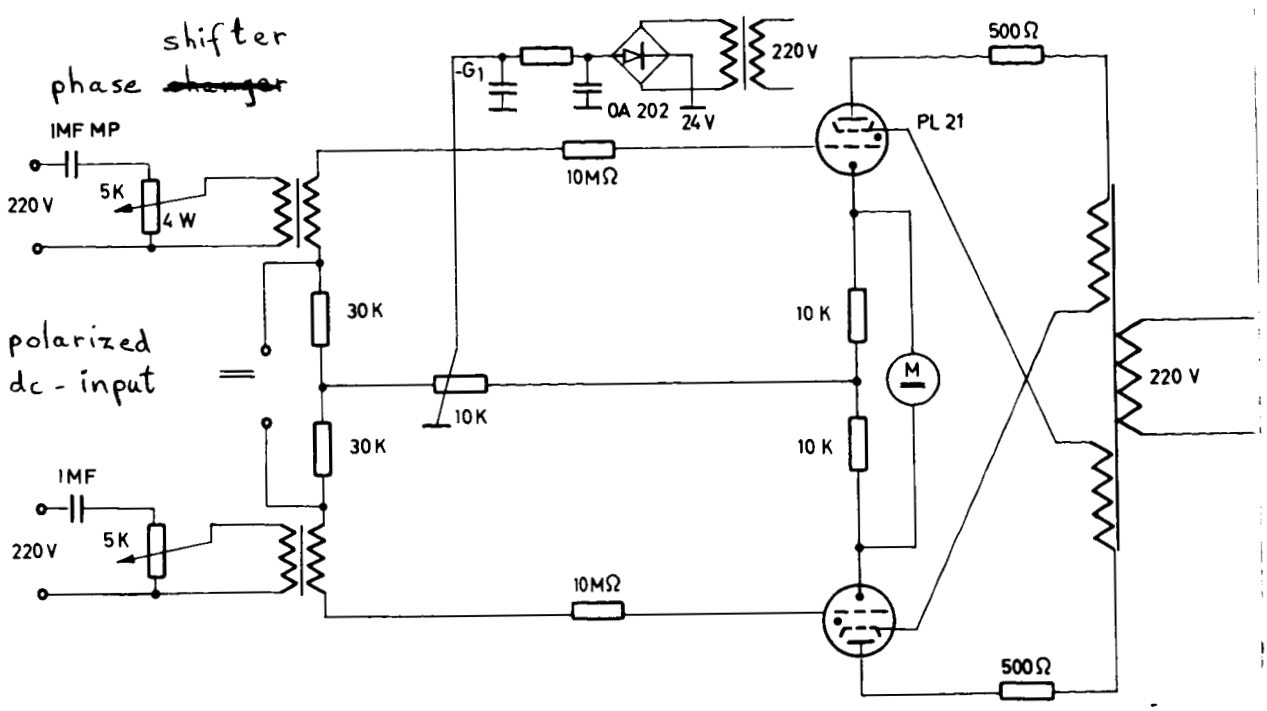

Figure 6. Thyratron servoamplifier for range-measurement instrument.

of frequency for fine measurement therefore depends essentially on the degree of accuracy with which the coarse system works.

3.6 The Response Function in the Aircraft

In the laboratory experiments, the phase shift of the path ground-aircraft-ground was simulated by a phase changer (over 360°). The latter (instrument No. 3 in figure 7) is similar to the resolver phase shifter in figure 4. With its aid, the properties of the control system can be measured (recorder No. 7 in figure 7) and optimalized The reception of the measurement frequency and its

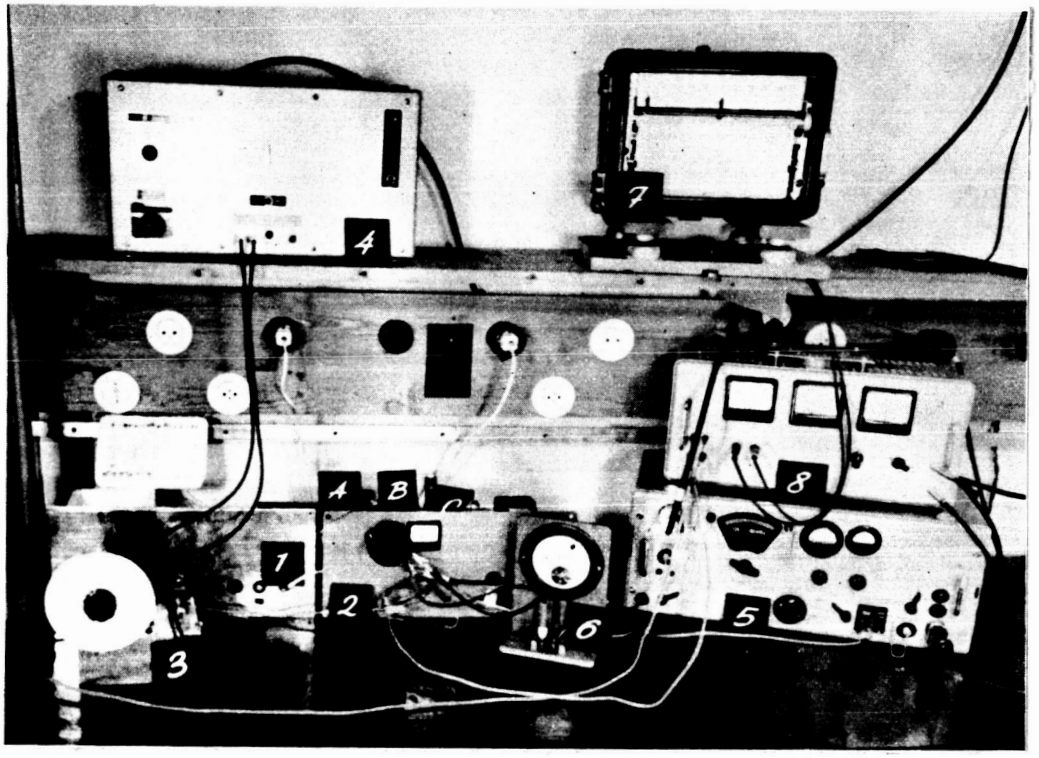

Figure 7. Laboratory installation for phase measurement of range-measurement system. Key: 1, tuning fork oscillator; 2, control instrument with A = servomotor, B = measurement resolver with potentiometer mounted, C = crystal oscillator; 3, phase shifter of resolver; 4, transmitter; 5, receiver; 6, phase-measurement distance (2-B instrument); 7, recorder; 8, test phasemeter.

modulation in a second radio instrument of different frequency poses no difficulties in principle.

However, for the practical utilization of such a range-measurement system, it is indispensable that the response of the aircraft takes place on the same frequency and with a standard radio-voice instrument, i.e., is transmitted as stored signal.

A simple phase storage is available in the tuning fork which is excited in-phase by the measured frequency received by the aircraft to its character-

istic frequency which must accurately agree with the measured frequency, and modulates the aircraft transmitter for a certain period of time after the end of reception.

In order to determine the properties of the tuning fork for this purpose, we constructed two tuning-fork oscillators respectively for 440 cps and 1000 cps (figure 8) and investigated the transmission levels necessary for exciting the tuning fork which becomes phase-stable in the shortest possible time, what build-up intervals are to be expected and what is the temperature trend for this mechanical oscilla-

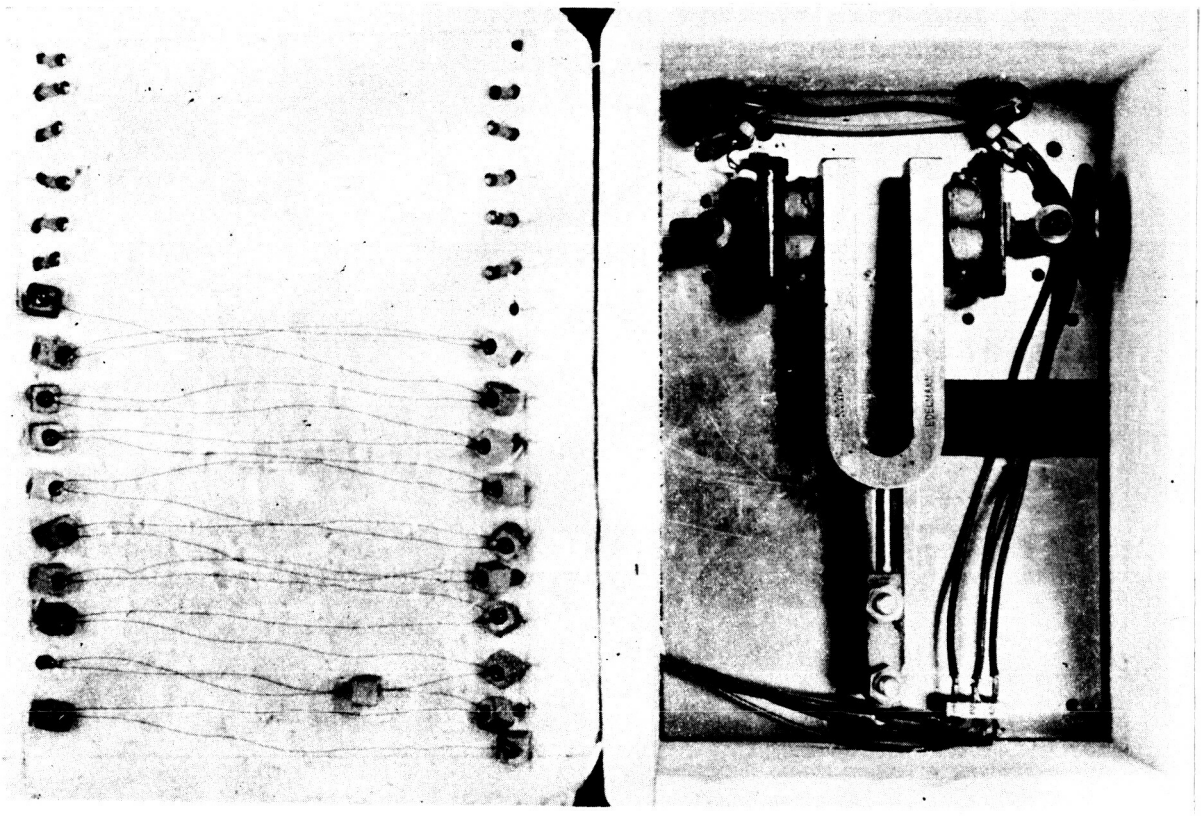

Figure 8. Experimental installation of a temperature-stabilized tuning-fork oscillator.

tor. Because the ground oscillator must moreover possess a frequency agreeing exactly with the tuning fork, the ground oscillator was converted from crystal control also to tuning-fork control in order to produce identical circumstances.

The experiments with tuning-fork storage have not yet been completed because the build-up time of the control circuit was not sufficiently short and was unable to compensate the existing frequency deviation of the aircraft oscillator from the ground oscillator. Funds for the construction of an improved tuning-fork oscillator were no longer available.

3.7 Results of Preliminary Experiments

The experiments have shown that the measurement installation described is suitable in principle for carrying out phase measurements. The weakest link in the phase detector utilized is, however, the phase measurement at zero phase. Considerable difficulties arise both from keeping the transmission level of the response frequency constant and the system is strongly subject to disturbances and deformation of the sinusoidal half-wave, e.g., by a minor but still existing distortion factor. For this reason, methods of phase measurement with the aid of the criterion of zero transition promise greater success for the present purpose (eventually transition to impulses in the measuring equipment). Work on this was interrupted because a new and extremely accurate phase-measurement principle is being developed and tested in the Institute for another mission.

Upon termination of this work, it will be possible to decide whether this principle is suitable for the present purpose. [20]

With the improvement of phase measurement, it will become necessary also to improve the control properties by turning to more accurate servoprinciples. After the limits of attainable accuracy in the coarse system have been deter-

mined, it will be possible to plan the fine system in regard to frequency and the instant of activation. Storage in the aircraft must further be tested in actual range-measurement operation.

In the meantime, Bendix has published the development of a similar range-measurement method for application to aircraft-ground and/or ground-aircraft (ref. 11). Technical details are still unknown except for the fact that this system also employs a tuning-fork storage.

4. Transmission of Characteristic Data Over the Radio-Voice Channel

4.1 Statement of the Problem

The problematics for a simplified automatic data-transmission system in regard to systematics lie in the restriction to a few and the most important data in a technique which connects up with existing methods and equipment and guarantees the possibility of later changes and additions.

The most important information on a flight is the flight number in the flight schedule which is sufficiently characterized by a three-digit number. If this is transmitted automatically, the speaking time of radio-voice communication is reduced in time by one routine information. Moreover, the continuous indication of this dentification during all radio-voice communication positively guarantees the identity of the respective aircraft.

The second (variable) information is the momentary barometric altitude.

This information is of importance above all because it is not measurable from the ground except for altitude-finding equipment in restricted air spaces) but is of vital importance for the control of the vertical stacking of air traffic in the traffic lane, especially at close distances. Its automatic transmission combined with the transmission of the identification number serves as control for the verbal indications of the pilot and [21]

appreciably increases, if the data transmitter possesses an integral altimeter, the reliability of this information. The more frequent incidence of information improves safety. An erroneous indication must be prevented by reliable data transmission.

4.2 Basic Technical Principle of the Characteristic-Data Transmitter

The ground equipment and the additional aircraft instruments in accordance with the above manner of operation were constructed in cooperation with the DVL by Rohde & Schwarz Co. in Munich with a view to immediate industrial production. The equipment consists of an aircraft device (figure 9) and a two-component ground device (figure 10). The altimeter integrated in the

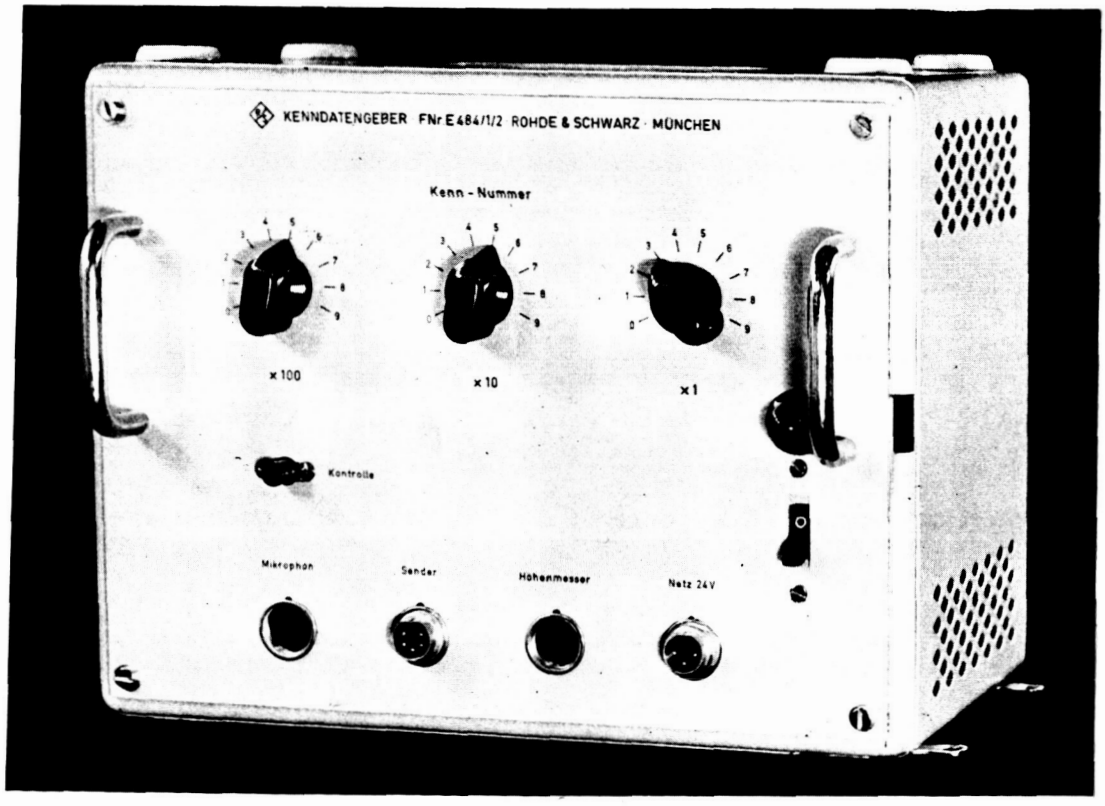

Figure 9. Aircraft instrument (characteristic-data transmitter) of the data-transmission installation.

aircraft equipment which furnishes the characteristic-data transmitter with a potential between 0 and 20 V, varying as a function of flight altitude, was constructed in the Institute from components of a meteorological radiosonde.

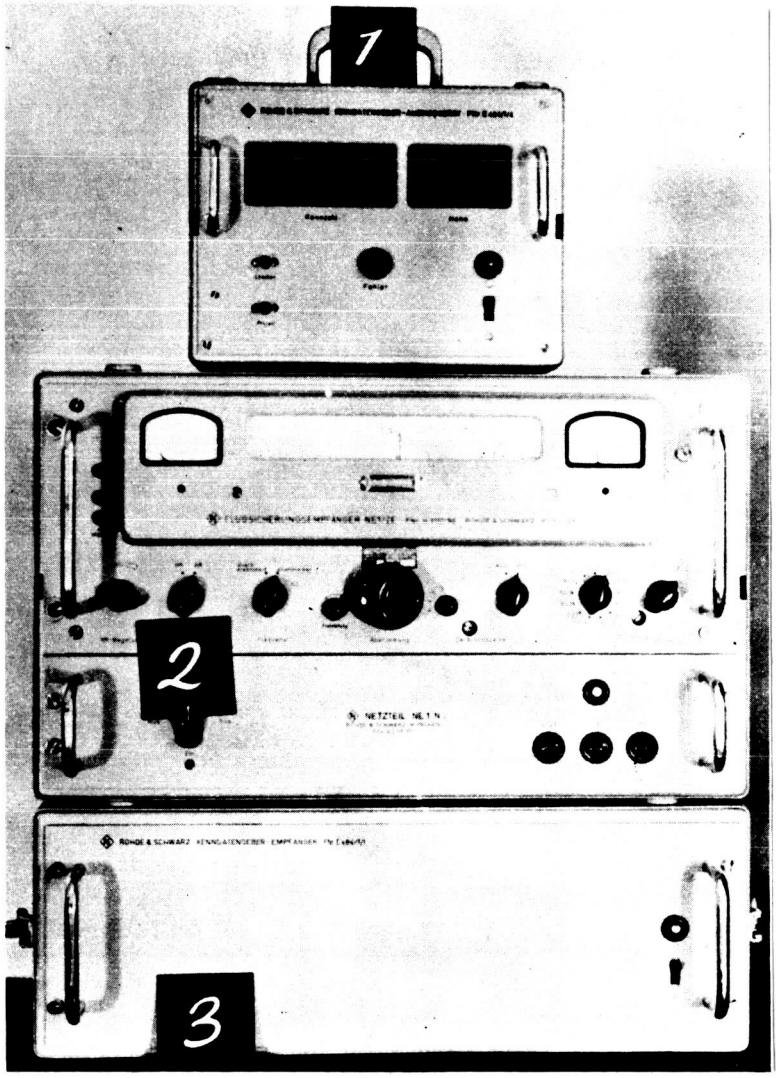

Figure 10. Ground instrument of the characteristic-data transmission installation.

Commercial altimeters with electric reading of the analog or digital value and with the required accuracy are constructed, however, generally as servoaltimeters and require a relatively high instrument expenditure, which cannot be justified for the preliminary orienting experiments.

a) Description of characteristic-data transmitter

With the aircraft-ground characteristic-data transmitter, it is possible, in conjunction with standard aircraft radio-voice equipment and a receiver, to transmit automatically an identification number consisting of three digits from 000 to 999 and the position of a potentiometer controlled by an aneroid barometer. Accordingly the altitude is represented in stages by 20 numbers from 00 to 19. The aircraft-ground characteristic-data transmitter consists of two devices, the aircraft device which is connected between the microphone with the microphone switch and the radio telephone and the two-component ground device which is controlled by the low frequency of the receiver of the ground station.

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The aircraft device (figure 11) is equipped with three 10-stage switches

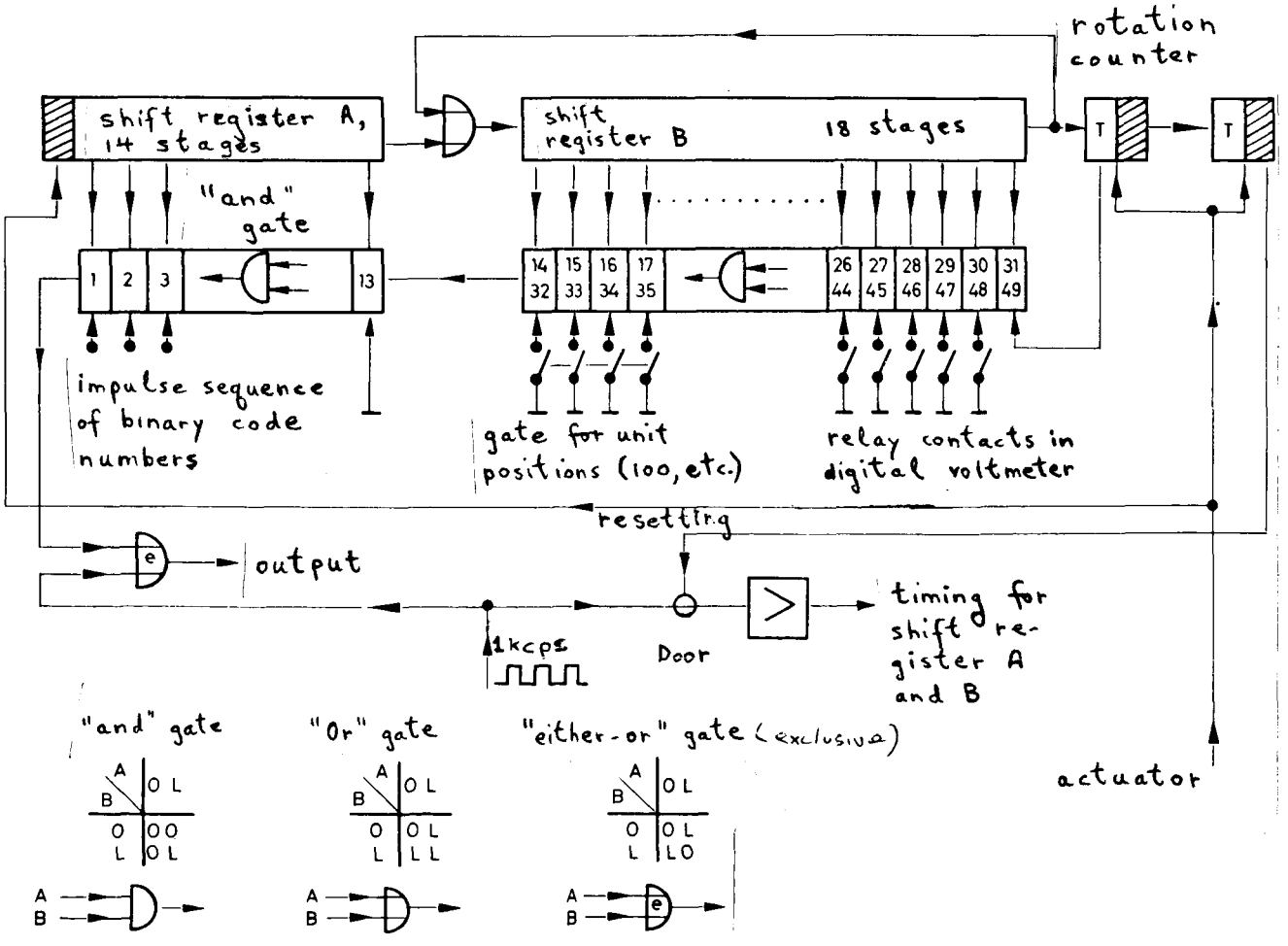

Figure 11. Circuit diagram of aircraft instrument.

with which the desired code number can be adjusted. It is also equipped with a simple digital voltmeter which measures the potential of the potentiometer whose position is adjusted by the altimeter, and is represented in digital form (figure 12). (The potentiometer position is not indicated in the aircraft device.) Another push button is provided which is connected in parallel with the microphone switch and with which the transmission of the characteristic data can also be activated. The radio telephone linked to the aircraft device can be utilized without change if the low-frequency range of the modulation amplifier possesses a frequency response of less than or equal to 3 dB between 400 to 2000 cps.

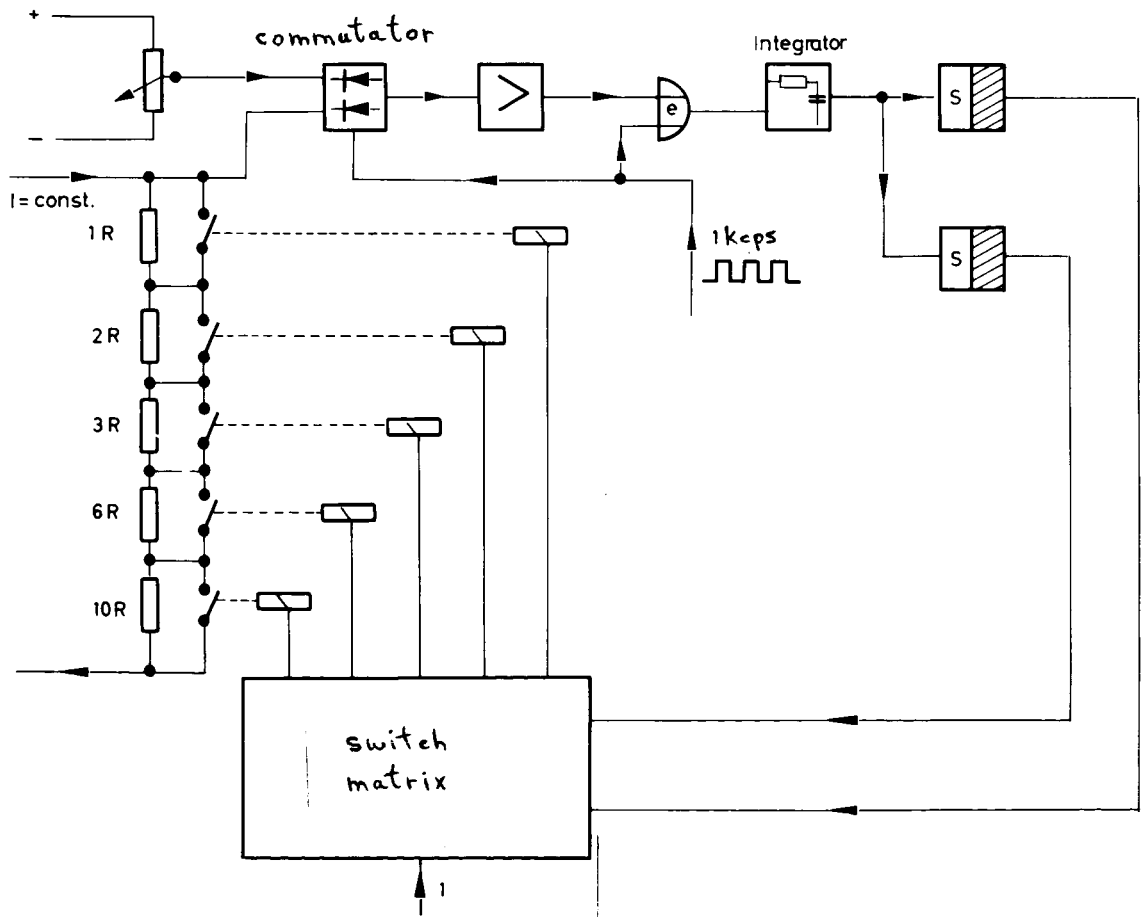

Figure 12. Circuit diagram of digital voltmeter.

The ground device (figure 13) consists of two components, the actual characteristic-data receiver containing all electronic devices and the indicator which contains the projection lights and a test and cancellation key. For control purposes, an additional characteristic-data transmitter is incorporated in the ground device where, however, the sequence of the numbers 7 8 9 - 10 is set up permanently as code number so that the switches and the digital voltmeter are eliminated. This control transmitter can be activated by the test key. A number indicated by the projection lights is automatically erased when new characteristic data arrive. Consequently it is not necessary to continually operate the cancellation key of the characteristic-data receiver for renewed recep-

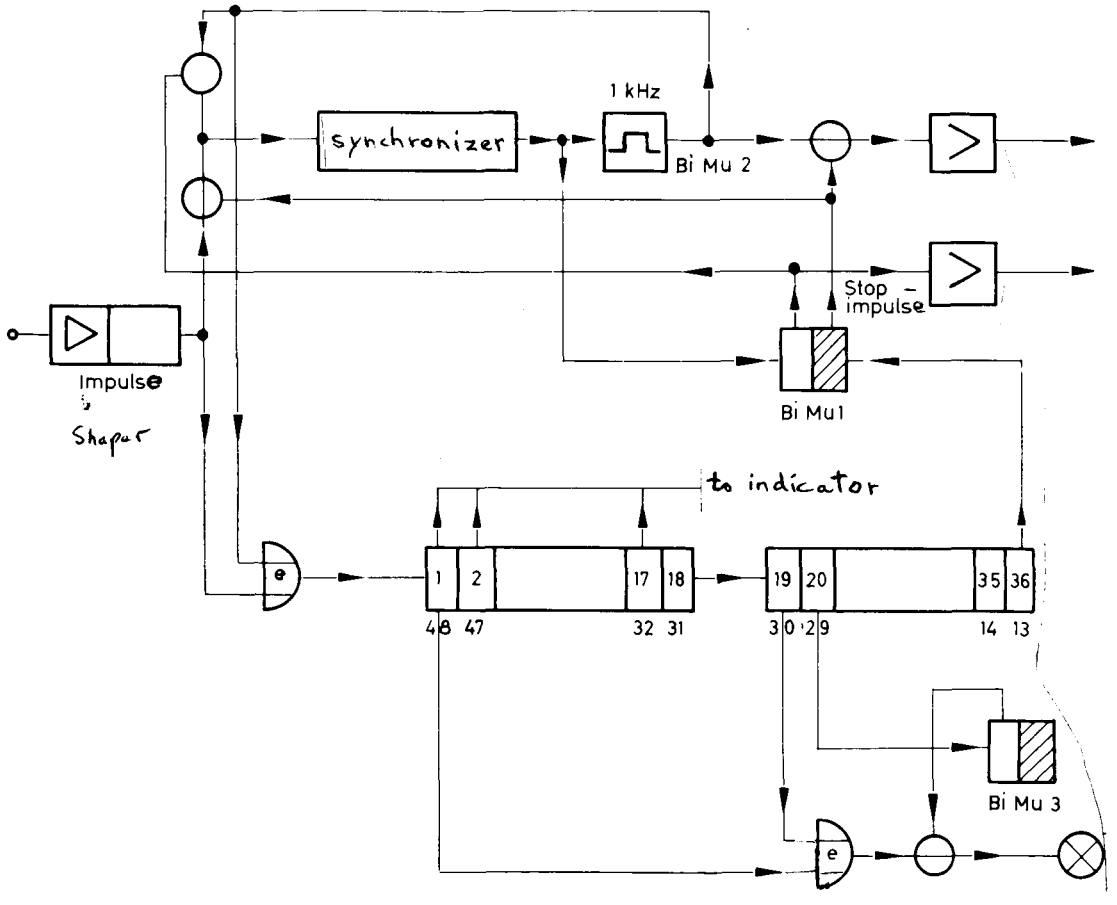

Figure 13. Circuit diagram of ground instrument.

tion. The cancellation key has been provided in order to be able to erase an indication no longer needed during intervals in operation.

b) The transmission system

The code number and the number for the potentiometer position are encoded in the aircraft instrument (circuit diagram in figure 11) by a binary sequence of numbers. Each number of the characteristic data is represented by four 123 binary digits. The code utilized is a six-, three-, two-, one-code, i.e., the value 6 is assigned to the first binary digit , the value 3 to the second, the value 2 to the third and the value 1 to the fourth. Since the number for the potentiometer positions has values only between 00 to 19 so that the first unit therefore is either 0 or 1, only one binary digit is sufficient for the first digit (binary 0 = "0", binary 1 = "L").

The signal speed for the transmission system has been selected as 1000 Bd (bands), i.e., transmission of 1 bit requires 1 msec. It would be possible to modulate the radio telephone directly with this impulse sequence. However, this is not very appropriate because the lower limit of frequency of the modulation amplifier would then be only a few cps. For this reason, we utilize a 1-kcps square wave as intermediate carrier which is switched in its phase.

By a simple logic circuit (an exclusive or gate) used for the impulse sequence, we obtain the modulation potential with an in-phase 1-kcps square wave (figure 11). On the receiver side, the original impulse sequence can be reobtained by connecting the modulation potential and an in-phase 1-kcps square wave to the input of a same logic circuit which furnishes the original impulse sequence at the output. For in-phase reception on the receiver side of the 1-kcps oscillation, ground and aircraft

stations must be synchronized. This is done by 12-zero impulses which are transmitted ahead of the characteristic data.

In order to have a simple but very effective control at the ground station over the accuracy of the received number, the characteristic data are repeated. In the ground equipment, the indicator is activated only then when both numbers agree in all units; if not, an error pilot light is illuminated.

After 48 steps, repetition is terminated. Step 49 is normally not needed but goes into operation in the event that the starting step (step 13) has become lost and the start is activated by the first "L" in the code number. Step 31 prevents an erroneous indication upon arrival, prior to step 13, of a start impulse simulated through radio interferences because then the actual starting impulse "L" is compared with step 31 "0" and the error indication is actuated.

With minor circuit changes, two different time schedules can be developed for the transmission system:

1. The impulse sequence is transmitted prior to the spoken information. In this case, the transmitter remains non-modulated for about 100 msec after activation of the microphone switch. This time is required for attenuation on the receiver side of all build-up processes of the amplitude regulation of the receiver. Only then is the impulse sequence transmitted.

Within 10 msec after the last step of the impulse sequence, the microphone is reconnected so that voice communication is established about 150 msec after activation of the microphone switch . Since the squelch controls of the receivers generally have a larger time constant, a perceptible interference with voice communication does not exist. However, it is then neces-

sary to derive the low frequency for the aircraft instrument directly after demodulation, i.e., ahead of the squelch control. If this should not be possible with certain aircraft receivers, the delay between connecting the aircraft instrument and the start of the impulse sequence must be enlarged.

2. The impulse sequence is transmitted after the spoken information. After activating the microphone switch, the microphone is connected to the modulator. Upon release of the microphone switch, the transmitter still remains connected. The microphone is disconnected from the modulator and, after an interval of 15 msec (relay ~~cushioning!~~ chatter), the impulse sequence is transmitted. The impulse sequence so obtained is now transformed into the modulation ~~potential~~ signal in the ~~either~~ exclusive-or gate whose second input is controlled by a 1-kcps ~~rectangular oscillation~~ square wave as already shown in figure 11. The commutation of the relays for the microphone switch-over has not been drawn separately. It was shown during the experiments that automatic transmission after radio-voice communication is preferable for technical reasons. 125

The potentiometer position of the altimeter is transformed in the aircraft instrument by a digital voltmeter into a digital value (circuit diagram 3 in figure 12). The potential from the potentiometer (the measurement potential) is conducted, alternately with a ~~comparison potential~~ reference voltage, to an amplifier. The change takes place by an electronic converter which is again controlled by a 1-kcps ~~rectangular oscillation~~ square wave. The ~~comparison potential~~ reference voltage can be changed in 20 stages with the aid of five relays. Initially, phase comparison of the output ~~potential~~ voltage of the amplifier with the 1-kcps oscillation controlling the electronic converter determines in an ~~either~~ exclusive-or gate whether the measurement ~~potential~~ voltage is larger, equal to or smaller than the

reference voltage. The output voltage of the exclusion gate is integrated in a RC-component. In this integration unit, the voltage can assume three values which have ratios of 0 : 0.5 : 1. This voltage controls two Schmitt triggers with thresholds respectively at 0.25 and 0.75. If the measurement voltage is smaller than the reference voltage, the two Schmitt triggers are at rest. If the measurement voltage is the same as the reference voltage, only one Schmitt trigger is in the on position (the lower) and, if the measurement voltage is higher than the reference voltage, both are in the on position. From these three different combinations, the five relays mentioned above are controlled by a switch matrix according to a simple relay converter principle. At a rate of approximately 1 cps, the reference voltage is increased and/or reduced in stages until it is equal to the measurement voltage. To this value is assigned a given combination of the positions of the five relays. The relays con- /26
trol the five "and"-gates for steps 26 to 30 and/or 44 to 48 during repetition exactly like the switches for the code number.

Function of Ground Instrument (circuit diagram in figure 13)

After minor amplification, resistance matching and impulse shaping the signal is separated in the ground instrument (characteristic-data receiver) and conducted to the synchronization circuit and the first input of an exclusion gate, serving for reobtaining the impulse sequence from the phase-modulated 1-kcps square wave. Synchronization furnishes a 1-kcps square wave in phase with the signal. This wave controls both the timing for a shift register and the second input of the exclusion gate. After the first synchronized impulse sequence, the shift

register is cleared. Subsequently, the remaining synchronization impulses are fed into the register step by step. Then the starting impulse and the characteristic data are fed to the register. After the starting impulse has reached position 18 of the shift register the impulse sequence for the code number and the potentiometer position are fully registered for the first time. After the starting impulse reaches position 20 of the shift register, a reference circuit is connected, which compares, respectively, position 1 and 19 of the shift register. In position 19, there is always an impulse of the first impulse sequence of the characteristic data and, in position 1 the corresponding impulse of the repetition. Comparison starts after the starting impulse. If the two stages do not agree, the timing is stopped immediately and the error pilot lamp lights up. In the normal case, however, the information is fully entered in the shift register for the second time. The shift cycle is stopped when the starting impulse reaches the last stage of the shift register. The numbers shown below the shift register indicate how the step numbers are distributed over the stages 1-36 of the shift register upon correct entry. /27 From stages 1-17 of the shift register we take the positions of the individual stages and conduct them to the indicator. The binary-encoded characteristic data are decoded here in a diode matrix and shown on the panel.

4.3 Laboratory Testing of Characteristic-data Transmission

The equipment described above was initially tested in the laboratory. As aircraft transmitter, operating with an artificial load we utilized a portable radio telephone instrument (Becker Company, Baden-Baden-Oos). This transmitter was also used in the aircraft during the subsequent tests

in flight. The ground equipment for the characteristic data was connected to a flight-control receiver NE-1 utilized in flight control. After eliminating some minor instrument deficiencies, the installation operated perfectly. The minimum received level was determined as 5 μV across 60 Ohm. Below this indication errors were noted.

For indication of the 19 different altitude stages, we constructed our own altitude sensor. For this we assembled two aneroid barometers from metereological radiosondes and connected them in series. This resolved the range of 0 to 4000 m attained with the measurement aircraft into 19 altitude stages. The axial expansion of the barometers was converted into a rotary motion for activation of a potentiometer so that, at a change of altitude from 0 to 4000 m, a nearly linear variation from 0 to 20 V resulted. Calibration was carried out in a pressure chamber where the accuracy evidently was shown as not particularly good. In particular, other values resulted for descending flight (rather than for climbing flight because of the excessive lag. This altitude indicator therefore served only for investigation of the manner of operation in principle.

4.4 Testing of Instrumentation in Flight

A number of tests in flight were undertaken with the same aircraft transmitter as in the laboratory tests. Initially, it was possible to obtain 128 satisfactory results only at small distances of the aircraft from the ground station (within a radius of 10 km). Beyond these distances, there occurred, in 50% of all cases, indication errors in spite of sufficiently high input voltages (red pilot light instead of the data to be indicated).

Initially we found no explanation for this because the instrument had proved satisfactory on the ground and the frequency utilized (our own test

frequency without other radio telephone traffic) was not subject to other interferences. Experimentally, the antennas of the two radio telephone instruments in the aircraft were interchanged. This lowered the rate of error to 10 %. The remaining 10 % of failures were determined to be due to a considerable lobing of the antenna pattern which caused partial loss of individual impulses. This could be confirmed by executing, at a great distance (with lower receiver-input voltages from the ground) certain flight maneuvers in which the transmitter antenna in its direction to the ground station travelled with high speed over those ranges which were characterized by considerable pattern lobing. It should be noted that the test aircraft was a small plane (Do-27) in which the risk of an unsatisfactory antenna pattern is appreciably greater than in large aircraft with carefully selected antenna position.

It was shown further that simultaneous radio telephone traffic arriving at approximately the same transmission level at the receiver leads in almost 80 % of all cases to distortion of the impulse information and to consequent loss of indication. However, this does not represent any interference in operation because simultaneous voice communication is also not possible and can be prevented by radio discipline. The test flights were carried out during descent and climb of the aircraft for investigation of the altitude-data transmission. If we disregard the low accuracy in resolution of the altitude stages, the result was satisfactory. It was observed further that the simple analog-digital converter principle developed is adequate for this purpose.

In order to obtain additional statistical material on the influence [29] of disturbances of all types on characteristic-data transmission, the instrument

was installed in a somewhat larger 2-engine aircraft (Queen Air) in order to obtain data outside of our specific measurement program for all flight schedules. The total time of flight tests has not yet been sufficiently long in order to obtain definite data on the total rate of error. Moreover, because of other flight measurements, a partial extension of the aircraft installation was necessary.

4.5 Conclusions from Present Findings

It was shown that characteristic-data transmission by the principle described is possible. In general, the impulse transmission of further data results in an appreciable reduction of the time required. If the data are of rapidly varying magnitude, their conversion to digital form may require in certain cases a greater expenditure than in the experimental arrangement.

The reliability of transmission through double transmission (parity check) is endangered in a greatly occupied frequency. However, since an indication error cannot occur, only the statistical loss rate is involved.

The range measurement described in section 4 requires, in operation with several aircraft, absolute selectivity of response. This would be guaranteed by coupling the range-measurement system with the characteristic-data system. Experiments in this direction have not yet been made.

We conclude from the presently known planning of future flight-control systems that the continuation of the present task initially appears doubtful. However, if we consider the fact that the traffic of the future -- including that of "general aviation" -- will have to be carried out essentially under IFR-conditions, there will always be a number of aircraft which cannot cooperate in the system. According to an American proposal for aircraft weighing more than 5.6 tons, the standard installation of a

"transponder" for a secondary radar is regarded as acceptable. Whether the existing gap can be closed by a simplified data-transmission system on the basis of the present design, cannot be stated definitely at this time because the requirements for such a system can be specified only after the entire flight-control system of the future has been determined in all details. Findings for this cannot be expected prior to 1970.

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5. Summary

The report describes, as possible complementary systems for existing and future flight-control systems, a range-measurement system and a simplified data-transmission system. Their operation in principle has been tested and improvements are necessary which could not yet be made due to inadequate financial means. Their incorporation in a flight-control system necessitates further development in an extended experimental operation. Further complementary installations in the aircraft and on the ground required by the cooperative character and operation with several aircraft will result from testing in practice. The continuation of the work is dependent on a decision for such a preliminary test operation. The work has been provisionally terminated. The possibility of the utilization of the two proposed complementary systems is herewith presented for discussion.

REFERENCES

1. Automatic Aircraft-to-Ground Communication System (AGACS) for Experimental Purposes of the Airways Modernization Board (AMB) (Automatisches Bord-Boden-Fernmeldesystem (AGACS) für Versuchszwecke des Airways Modernisation Board (AMB)). AMB-Druckschrift AMB-CD 1-58, February 17, 1958.

2. Agenda Items 10.3, 10.4, 11.2 of the Seventh Meeting of ICAO, Communications Division, Montreal, January-February 1962.

3. Report of the Task Force on Air Traffic Control. A Study of the Safe and Efficient Utili ation of Airspace. Project Beacon, Federal Aviation Agency, October 1961.

4. Report of the Special Committee for Air-Traffic Control. "Project Beacon" - A study on safe and effective utilization of air space. (Bericht der Sondergruppe für Luftverkehrs-kontrolle. Eine Studie über die sichere und wirkundsvolle Ausnutzung des Luftraumes – "Project Beacon"). Federal Aviation Agency, October 1961.

5. On the Recognition of Friend and/or Enemy By Means of Secondary Radar (Zur Freund/Feind-Erkennung mittels Sekundärradar). Technisches Informationsblatt 1/64, Fernmeldedienst der Bundeswehr.

6. Harris, K. E. Some Problems of Secondary Surveillance Radar Systems. Journal of the British Institution of Radio Engineers, July 1956, pp. 355 - 382.

7. Archer, H. R. ATC and Royal Radar. World Aviation Electronics, November 1963, pp. 662 – 673.

8. Battell, W. J. A Digital Data Link for Aircraft Communication. The Radio and Electronic Engineer, April 1964, pp. 315 – 323.

9. Zetzmann, H. J. Contributions of the Siemens Company to Flight-Control Techniques and Aviation Electronics between 1930 and 1945 (Beiträge der Firma Siemens zur Flugsicherungs-Technik und Luftfahrtelektronik in den Jahren 1930 bis 1945). Frequenz 9, 1955, No. 9, pp. 351-360 and No. 10, pp. 361-370.

10. Rescher Handbook. Resolver Instrument Corporation, a Subsidiary of Dynamics Corporation of America, 215 E. 91st Street, New York 28, New York, U.S.A.

11. Allison, D. M. Range Measurement with Standard Aircraft Communication Equipment. Bendix Radio Corporation, Baltimore 4, Maryland, U.S.A., 1961.

12. Automatic Altitude Transmission (Automatische Höhenmeldung). Aircraft-Equipment Division, Pioneer Central Division of Bendix Corporation, U.S.A.